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Study on Preparation of CrSi Thin Film Resistance by Magnetron Sputtering

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Abstract: Thin films prepared by magnetron sputtering can overcome the shortcomings of electron beam evaporation and have the advantages of film thickness control, adhesion, density, conductivity and refractive index, etc. This paper uses the method of literature research and review to clarify the specific process influencing factors in the preparation of CrSi films by magnetron sputtering and subsequent annealing. It provides a reference basis for the integrated application of CrSi thin film resistors.

Keywords: Magnetron Sputtering; CrSi Thin Film; Annealing Process.

1. Introduction

Metal film resistors have good stability and high precision, they are widely used in analog integrated circuits. In recent years, researchers have paid particular attention to materials such as CrSi, TaN and NiCr, looking for ways to further improve the stability of electrical metal films. Among them, CrSi thin film resistance has the advantages of large resistance value, good stability and small resistance temperature coefficient, so it is widely used and selected as the key research object in the field of thin film resistance application [1-3]. The preparation of CrSi thin film resistors by magnetron sputtering can not only improve the film characteristics, produce high-quality thin film resistors, improve the performance of integrated circuits, but also bring higher stability and reliability to military aerospace products [4].

In this paper, the effects of sputtering conditions, such as sputtering power, sputtering pressure, substrate heating temperature, process gas volume flow rate and subsequent annealing parameters on the film resistance during the preparation of metal films were studied, which provided a reference for the industry to obtain high stability and reliability of CrSi metal films.

2. Properties and Characterization of CrSi Films

2.1. CrSi Conductive Mechanism

The electrical transmission of thin film resistance can be divided into two parts: one is the transmission inside the grain; The other part is the transport between grains. It is assumed that the transport within the grain is continuous metal film, and the transport between the grains is activated tunnel effect. The essence of activating the tunneling effect is to combine the mechanism of thermal activation of carriers with the tunneling effect, the main content of which is that electrons move from one neutral island to another neutral island so that some of the original neutral islands are charged. The electron transmission between the electric island and the neutral island is a tunnel process, and the tunnel process is more sensitive to the distance between the islands. The electron scattering resistivity inside the grain increases with the increase of temperature, resulting in a positive temperature coefficient of resistance. The higher the insulating phase temperature between grains, the higher the energy obtained by electrons, and the more electrons that tunnel through the barrier resulting in a negative temperature coefficient of resistivity. The final temperature coefficient of the film resistance is the result of two competing trends [5-6].

2.2. TCR

The physical meaning of TCR is the relative change rate of resistance value of resistance (R) when the temperature changes by 1℃. TCR (resistance temperature coefficient) is an important parameter of the film resistance, and its value reflects the stability of the film resistance under the condition of temperature change. It is found that TCR is closely related to the film forming process and heat treatment conditions. In the determined film forming process, finding the best heat treatment conditions to obtain the lowest TCR and stable resistance change △R (%) is the ultimate goal of the film resistance process [2,6].

3. Technological Parameter

3.1. Sputtering Pressure

In order to obtain a stable sputtering current during the sputtering process, a certain pressure of working gas must be filled into the vacuum chamber. It was found that 0.24Pa is the critical pressure that can be discharged, and generally controlled at 0.267 ~ 0.320Pa is the ideal working pressure for sputtering. The higher the working pressure is, the more kinetic energy will be lost in the collision, which will affect the densification of the deposition film and even result in the larger oxidation component of the AlSi film. After heat treatment, Mo-AlSi and other phenomena appear which affects the stability and reliability of the source device. The working pressure is too low to play the role of glow discharge, which is also cannot reach the ability to bombard the target, thereby cannot play the role of coating.

3.2. Sputtering Power

Under a certain pressure, the sputtering rate strongly depends on the size of the sputtering current. Raising the sputtering current means the increase of sputtering power increases the ionization rate of Ar gas which results to the increase of the sputtering rate. Thereby the covering ability, adhesion ability and density of the substrate surface are improved, and the corresponding sputtering time is shortened, the substrate surface pollution is reduced, ultimately the film quality is improved. On the contrary, if the sputtering power is low, the speed is slow, the adhesion of the film is poor, the structure is loose, and the step coverage is not good, which affects the quality of the film. Practice has proved that the general sputtering current should be controlled within 5.5 ~ 6.5A, and the voltage should be controlled within 0.4 ~ 0.5kV [5]. Fig.1 shows the relationship between sputtering power and resistance temperature coefficient by experiments.

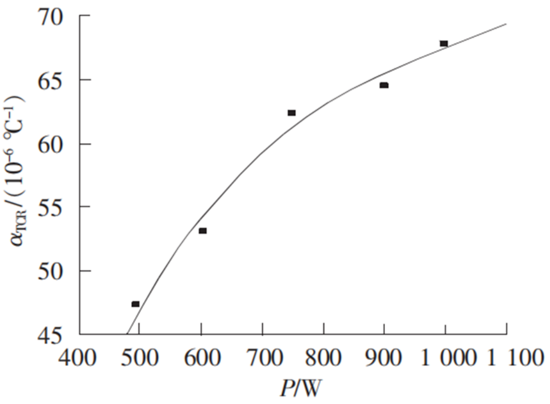

Fig 1. Relationship between sputtering power and resistance temperature coefficient

3.3. Substrate Heating Temperature

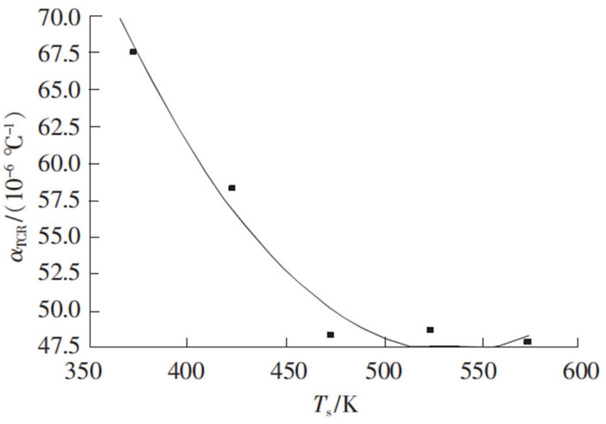

Fig 2. Relationship between substrate heating temperature and resistance temperature coefficient

Substrate temperature is one of the important factors affecting the grain size of film forming. Under the same sputtering pressure, the grains of sputtering film gradually increase with the increase of substrate heating temperature. This is because the higher the substrate temperature, the higher the energy of transverse movement of target atoms sputtering to the substrate is, the stronger the transverse movement activity is, the easier it is to condensed into large grains, and the grain spacing becomes larger. The negative temperature coefficient increases, and the overall temperature coefficient changes to the negative temperature coefficient. Besides if the baking temperature is too low, the substrate adsorbs some active gases, trace oil molecules as well as water vapor. The residual activity gas on the wall of the vacuum chamber is not released; If the baking temperature is too high, it will cause a new oxide layer to the clean chip lead hole, which cannot get a good ohmic contact, increase the DC parameters of the circuit V_{CD} and V_{eb} voltage drop, resulting in a small Schottky forward and reverse breakdown soft. Practice shows that the baking temperature is generally between 100 and 180°C. Fig.2 shows the relationship between substrate heating temperature and resistance temperature coefficient by experiments.

3.4. Gas Volume Flow

The experimental research found that the larger the argon pressure during sputtering, the larger the grain size. The sputtering argon pressure and the volume flow into the process chamber (argon gas) are in a positive ratio, so the influence of substrate temperature increase on the temperature coefficient of CrSi film resistance is similar to that of substrate temperature increase. The positive temperature coefficient of CrSi film decreases with the increase of grain resistance and the increase of grain spacing. The relationship between the volume flow rate (qV) of different sputtering processes and the temperature coefficient of the resistance of the sputtered CrSi films is shown in the Fig.3. It can be seen from Fig.3 that with the increase of volume flow volume of spatterized gas body, the temperature series of the electrical resistance of CrSi film decreases. When the volume flow rate of gas body is 70cm^3 / min, the minimum temperature coefficient of resistance of CrSi film is about 1.5 $\times 10^{-5}$ / °C. Fig.3 shows the relationship between gas volume flow and resistance temperature coefficient by experiments.

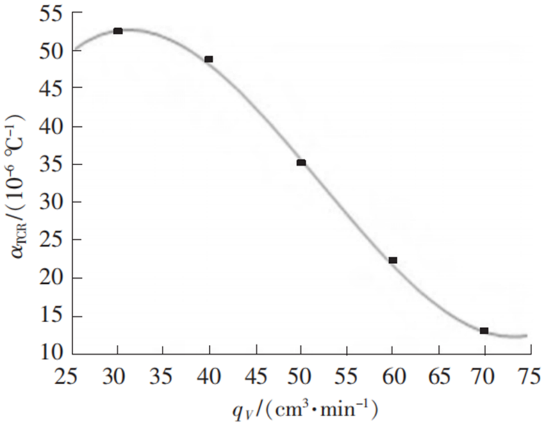

Fig 3. Relationship between gas volume flow and resistance temperature coefficient

3.5. Volume Flow of Reaction Gas

When sputtering, the reaction gas nitrogen or oxygen is added, which helps to adjust the temperature series of CrSi film resistance and improve the stability of CrSi film resistance. Due to the incorporation of nitrogen elements in the sputtering process, silicon nitride is formed on the substrate. This insulating medium increases the distance between the resistance grains of the CrSi film. From the conduction mechanism of CrSi films, the negative temperature coefficient between the resistive grains of CrSi films increases with the increase of nitrogen flow rate. The volume relationship between the volume flow rate of added nitrogen (qV, N_2) and the temperature coefficient of the sputtered CrSi film resistance is shown in Fig.4. As can be seen from Fig.4, with the continuous increase of nitrogen volume flow rate in reactive sputtering, the temperature coefficient of CrSi film resistance decreases continuously. When the volume flow rate of nitrogen is less than 0, the temperature coefficient of CrSi film resistance is the closest to 0, which is -3.88 $\times 10^{-6}$ / ℃. It is the smallest value of temperature coefficient in the CrSi film resistance prepared in this experiment. It can be considered that this sputtering condition is the most suitable optimization condition for CrSi grain size and CrSi grain spacing.

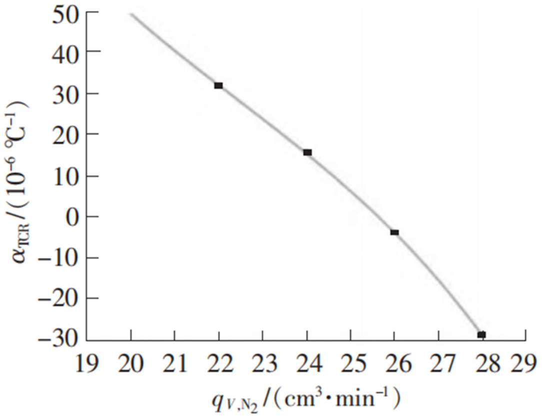

Fig 4. Relationship between reaction gas volume flow and resistance temperature coefficient

3.6. Annealing Process

In order to improve the stability of the resistance of CrSi thin film, high temperature annealing treatment is generally used after the deposition. On the one hand, the purpose is to accelerate the disappearance of defects, unsteady structure and internal stress in the film so that the resistance of CrSi film is in a stable state to improve the long-term stability of the film. On the other hand, a certain amount of insulating phase is formed in the film to improve the temperature characteristics of the film. It can be seen from the annealing temperature experiment that the higher the annealing temperature, the higher the temperature coefficient of CrSi film resistance and the worse the stability. The addition of appropriate oxygen in the annealing atmosphere can reduce the temperature coefficient of CrSi film resistance and improve the stability of CrSi film resistance.

4. Conclusion

In this paper, the important influencing factors in the preparation process of CrSi thin film resistance by magnetron sputtering are studied; The influencing rules of various factors are summarized from the perspective of theory and experimental analysis, which provides a favorable reference for improving the preparation process of metal thin film resistance.

References

[1] J.J.ZHU, Z.L. Zhang, N.L.He: Electrical properties of CrSi thin film resistors for high precision analog circuits. 2022 10th International Symposium on Next-Generation Electronics (2023), 10221639.

[2] Jiang Wei, Tang Junfeng: CrSi thin film resistance technology by sputtering method, discussed at the 14th National Hybrid Integrated Circuit Academic-Huangshan, Anhui, China (2005):p.124-130.

[3] J.J. Zhu , Z. L, Zhang, L.H. Gu: Fabrication process and variation rule of electrical properties of CrSi thin film resistors, Journal of Physics: Conference Series, Vol.2680 (2024), p.1-6.

[4] Kong Lingying: Process factors affecting the quality of magnetron sputtering film, Semiconductor Technology, 1997 (5): p.21-23.

[5] Wang Fei, Chen Jun, Wang Xue-Yi: Preparation of CrSi thin film resistance with low temperature coefficient, Micro and Nano Electronic Technology, Vol. 54 (5), 2017: p. 355-359.

[6] Luo Shan, Zhang Zhengyuan: Optimization of resistance annealing conditions for CrSi thin films, Microelectronics, Vol38 (3), 2008: p. 316-319.